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Sex determination by the length of metacarpals and phalanges: X-ray study on Egyptian population

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ABSTRACT

Measurements of hand bones length have been shown to be sexually dimorphic in many nationalities. The aim of this study is to assess the accuracy of sex determination from the length of all metacarpals and phalanges of right and left hands using X-ray radiographs and to develop a discriminant formula that can be used in the Egyptians. One hundred Egyptians are included in the study (50 adult males and 50 adult females) in the period from December 2009 to January 2011 with mean age 31.60 ± 9.44. Each is subjected to X-ray radiographs on both hands. The results reveal that males have significantly greater mean values than females for all metacarpals and phalanges of both hands and the Egyptian population has greater measurements in comparison to the other ones (e.g. Turkish and European Americans). In addition there is no significant difference between the right and the left hands in either males or females. The correct classification reached an accuracy of 88%–94% by using both hands, while that for right hand only is 88% and 88%–90% for the left hand only. Regarding the accuracy of each bone, the present results revealed that 1st DP & PP and 3rd and 4th MC in the right and left hands are the best bones that can be used in correct sex determination. It is concluded that the length of metacarpals and phalanges *(especially the 1st DP & PP and 3rd and 4th MC)* could be used for sex determination. The right hand could be used as the left hand in determination of sex. Also the X-ray radiographs are good non invasive and simple tool in the determination of sex from the hand bones. Furthermore the regression equation for both hands and each hand separately is specific to Egyptian population and should be used after validation of the results in other ones.

1. Introduction

The determination of race, sex, age and stature in the living or dead is an imperative element of any medico-legal investigation. Sexing of the remains is a cornerstone in forensic medicine as it primarily narrows down the pool of possible victim matches.[1,2]

Sex estimation is the classification of an individual as either male or female. To achieve an assignation of sex, anthropologists use biological traits that vary between both sexes. Although there are only two biological sexes exist in humans, sex estimation of a human skeleton remains a challenge.[3]

There are variable techniques for detection of age and stature which are sex dependent. Sexing is one of the simplest tasks in forensic analysis when the external and internal genitalia can directly suggest the sex of an individual. Sex differentiation remains, however, a complex one in cases of intersex (where there is a discrepancy between the external genitals and the internal genitals); advanced state of putrefaction and mutilated, fragmentary or skeletonized remains.[4–6]

With the increasing frequency of mass disaster, natural or otherwise, it is not uncommon to find dismembered human remains and peripheral parts of the body.[2,7,8] For this purpose, anthropologists developed sexing methodology based on human bones. While the most useful bones in this regard are cranial and pelvic ones, these are not always available.[9] In the instance of incomplete or damaged skeletal remains, the sex determination can be attempted from other bones which show some degree of sexual dimorphism.[10,11] As regard sexual dimorphism in human sternum; although manubrium of the two sexes is of almost equal length, the mesosternum is proportionately longer in males than in females.[10]

Anatomically the short tubular bones have some advantages over other bones in a forensic context. The shafts of long bones

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often stay intact, but their epiphyses are prone to damage because of the overlying fragile cancellous bone. However, the smaller long bones of the hands often remain complete.[2,12]

The hands, especially the metacarpal bones, have been addressed for sex estimation with varying results in terms of accuracy.[4,13,14] Previous studies have, with variable accuracy, shown that the metacarpals are useful for the sex determination of skeletal remnants. This variation was attributed to many factors including racial or population variances. There have been fewer studies on phalanges for the same purpose, although their accuracy has been found to be longer than that of metacarpals.[15,16] Manolis et al.[13] mentioned that the accuracy of metacarpal bones in was ranged from 72.3%–88.9%, while Eshak et al.[4] stated that the accuracy of metacarpal bones was ranged from 71.4 % to 92.9% and the accuracy of phalanges was ranged from 50 % to 83%.

This study was designed to assess the accuracy of sex determination from the length of all metacarpals and phalanges of right and left hands using X-ray radiographs and to develop a discriminant formula that can be used in the Egyptians.

2. Subjects & methods

2.1. Subjects

This study was conducted on 100 Egyptian subjects (3800 bones) classified to 50 adult males (their ages range from 17 to 53 years) and 50 adult females (their ages range from 17 to 65 years). The study spanned the duration between December 2009 to January 2011. Subjects were randomly chosen including every third patient who required a hand radiograph among those attending the Radiology Center in Mansoura University Hospital. Subjects were excluded clinically but sometimes cases were excluded when radiographs showed radiological skeletal immaturity, pathological lesions such as congenital and developmental dysplasia, metabolic bone diseases, recent trauma, recent surgery, bone tumors, osteoarthritis or arthritis (Done by the second author; consultant radiologist & professor of Anatomy).

2.2. Methods

Right and left hands were radiographed in all subjects after obtaining informed consent as approved by the Institutional Research Ethics Committee. The subject was seated adjacent to the X-ray table after wearing protective clothing with the forearm and hand flat and prone on the table with no lateral angulations at the wrist. The hand was centered on the cassette with fingers slightly apart from each other but flat. Images were obtained using a small focal point and a detail cassette. Exposures and distances were: 48 kV; 3.2 mA s; 90 cm source to image distance.

The length of all metacarpals and phalanges (proximal, middle and distal) of all fingers of the right and left hands were measured manually *(in millimeters)* on the X-ray films by one observer (First author). All measurements were repeated at the middle and end of study to avoid any intra − observer error and the differences between measurements found to be small and not statistically significant (data not shown). All measurements were made from the midpoint of the base to the midpoint of the tip of all metacarpals and phalanges.[17]

2.3. Statistical analysis

The statistical analysis of data was done by using SPSS (SPSS, Inc, Chicago, IL) program statistical package for social science version 16. To test the normality of data distribution K–S (Kolmogorov–Smirnov) test was. All tested data revealed to be parametric.

All results were expressed as mean ± standard deviation (SD), minimum and maximum values. The analysis of the data was done to test statistical significant difference between groups. For quantitative data student *t*-test was used to compare between two groups. Multivariate logistic regression analysis was used in order to be able to predict sex based on values of predictor variables of the metacarpals and phalanges. To detect the cutoff values with highest sensitivity and specificity for each bone the Roc *(Receiver Operating Characteristics)* curve was done. p was considered significant if ≤ 0.05.

3. Results

Descriptive analyses of age of the subjects are summarized in Table 1. The mean ± SD age for male subjects is 31.86 ± 8.87 years (ranges from 17 to 53 years) while mean ± SD age for female subjects is 31.34 ± 10.07 years (ranges from 17 to 65 years).

The summary statistics and comparison for all measurements (minimum, maximum, mean ± SD) of the right and the left hand bones *(in millimeters)* between both sexes are presented in Table 2. All measurements are significantly higher in males than females regarding all metacarpals and phalanges of both right and left hands.

A comparison between the right and the left hand bones in males and females by using student *t*-test is represented in Table 3. There is no significant difference between the right and the left hand in either males or females except for the first metacarpal bone in males.

Multivariate logistic regression analysis with the use of most predictable measurements of both hand bones to determine sex is demonstrated in Table 4. As a result 94% of the males (47/50) and 88% of the females (44/50) are correctly classified by using both hands as shown in Table 5.

Furthermore multivariate logistic regression analysis with the use of most predictable measurements of the right hand and the left hand bones separately to determine sex is demonstrated in Table 6.

While 88% of both males and females (44/50) are correctly classified by using the right hand only and 90% of males (45/50) and 88% of females (44/50) are correctly classified by using the left hand only Table 7.

In addition, the cut off values (in mm) and accuracy percentage for sex determination for each bone in the right and left hand is illustrated in Table 8.

So for determination of sex (z), the following equation is used where $z = 0$ for males and $z = 1$ for females, was regressed on the bone measurements (Lf PP1, Lf MC4, Rt PP2, Rt PP3 and Rt PP4) to produce equations with the generalized formula. z = Constant (53.584) + B (−1.746) X (PP1) + −0.640 X MC4 + 1.559 X PP2 + −1.310 X PP3 + 0.815 X PP4.

If $z > 0.5$, the bone is male, and, if $z < 0.5$, the bone is female.

Fig. 1. Illustrates the measurements of all the metacarpals and phalanges of the right and the left hands *(in millimeters)*.

Table 1
Descriptive statistics of the studied subjects ($n = 100$) by means of age.

	Minimum	Maximum	Mean ± SD
Males ($n = 50$)	17	53	31.86 ± 8.87
Females ($n = 50$)	17	65	31.34 ± 10.07
Total ($n = 100$)	17	65	31.60 ± 9.44

Table 2
Summary statistics (minimum, maximum, mean ± SD) and comparison for all measurements of the right and the left hand bones (in millimeters) between both sexes ($n = 100$).

Bone Rt			Fingers									
			1st		2nd		3rd		4th		5th	
			Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
DP	Range	Male	18.00	28.00	15.00	21.00	16.00	23.00	16.00	29.00	14.00	22.00
	Mean ± SD		23.14 ± 1.81		17.92 ± 1.58		19.26 ± 1.81		20.04 ± 2.19		17.80 ± 1.52	
	Range	Female	17.00	24.00	14.00	27.00	15.00	28.00	15.00	23.00	12.00	19.00
	Mean ± SD		20.32 ± 1.46		16.44 ± 1.92		17.26 ± 2.02		17.78 ± 1.68		15.72 ± 1.42	
		t	8.544		4.188		5.194		5.755		7.037	
		P	0.000*		0.000*		0.000*		0.000*		0.000*	
MP	Range	Male	None		20.00	30.00	25.00	36.00	25.00	33.00	17.00	25.00
	Mean ± SD				24.28 ± 2.14		29.82 ± 2.33		28.58 ± 1.99		20.62 ± 1.73	
	Range	Female	None		19.00	27.00	21.00	38.00	22.00	38.00	15.00	29.00
	Mean ± SD				22.64 ± 1.71		27.20 ± 2.71		26.58 ± 2.51		18.52 ± 2.36	
		t	None		4.222		5.169		4.408		5.058	
		P			0.000*		0.000*		0.000*		0.000*	
PP	Range	Male	29.00	38.00	35.00	47.00	41.00	52.00	38.00	49.00	31.00	40.00
	Mean ± SD		32.96 ± 2.24		41.58 ± 3.03		46.72 ± 2.77		43.70 ± 2.71		34.90 ± 2.26	
	Range	Female	25.00	33.00	35.00	52.00	37.00	48.00	37.00	44.00	28.00	36.00
	Mean ± SD		28.98 ± 2.06		38.92 ± 2.97		42.76 ± 2.59		40.44 ± 2.13		32.12 ± 1.97	
		t	9.216		4.424		7.360		6.661		6.547	
		P	0.000*		0.000*		0.000*		0.000*		0.000*	
MC	Range	Male	43.00	55.00	63.00	80.00	60.00	77.00	54.00	69.00	49.00	63.00
	Mean ± SD		48.44 ± 2.74		71.58 ± 3.93		68.62 ± 3.72		60.66 ± 3.35		56.72 ± 3.35	
	Range	Female	39.00	51.00	58.00	72.00	55.00	70.00	49.00	61.00	45.00	59.00
	Mean ± SD		44.64 ± 2.97		65.34 ± 3.43		62.28 ± 3.47		54.44 ± 3.11		51.56 ± 3.16	
		t	6.634		8.452		8.799		9.604		7.903	
		p	0.000*		0.000*		0.000*		0.000*		0.000*	
Bone Lf			Fingers									
			1st		2nd		3rd		4th		5th	
			Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
DP	Range	Male	14.00	27.00	15.00	22.00	16.00	23.00	16.00	23.00	14.00	21.00
	Mean ± SD		22.68 ± 2.10		18.08 ± 1.58		19.26 ± 1.71		19.82 ± 1.74		17.80 ± 1.57	
	Range	Female	16.00	23.00	14.00	21.00	15.00	22.00	16.00	22.00	14.00	19.00
	Mean ± SD		20.28 ± 1.48		16.34 ± 1.43		17.38 ± 1.52		17.90 ± 1.37		15.76 ± 1.22	
		t	6.590		5.743		5.800		6.111		7.229	
		P	0.000*		0.000*		0.000*		0.000*		0.000*	
MP	Range	Male	None		20.00	29.00	25.00	35.00	25.00	33.00	17.00	25.00
	Mean ± SD				24.24 ± 2.01		29.80 ± 2.26		28.56 ± 1.96		20.58 ± 1.83	
	Range	Female	None		20.00	27.00	21.00	31.00	23.00	37.00	15.00	22.00
	Mean ± SD				22.62 ± 1.66		27.12 ± 2.08		26.44 ± 2.33		18.66 ± 1.74	
		t	None		4.382		6.150		4.921		5.368	
		P			0.000*		0.000*		0.000*		0.000*	
PP	Range	Male	29.00	38.00	36.00	48.00	41.00	52.00	39.00	50.00	30.00	40.00
	Mean ± SD		33.00 ± 2.18		41.78 ± 2.67		46.98 ± 2.79		44.02 ± 2.72		34.94 ± 2.23	
	Range	Female	25.00	33.00	35.00	44.00	38.00	48.00	37.00	45.00	28.00	37.00
	Mean ± SD		28.98 ± 1.93		38.72 ± 2.15		42.94 ± 2.60		40.34 ± 2.03		31.96 ± 2.19	
		t	9.744		6.296		7.474		7.655		6.727	
		P	0.000*		0.000*		0.000*		0.000*		0.000*	
MC	Range	Male	43.00	55.00	64.00	80.00	61.00	77.00	53.00	69.00	50.00	64.00
	Mean ± SD		49.02 ± 2.86		71.98 ± 3.80		68.76 ± 3.72		60.88 ± 3.52		56.46 ± 3.22	
	Range	Female	39.00	51.00	57.00	72.00	56.00	70.00	50.00	60.00	44.00	57.00
	Mean ± SD		44.60 ± 2.72		65.30 ± 3.18		62.18 ± 3.29		54.68 ± 2.75		51.36 ± 3.04	
		t	7.900		9.507		9.353		9.792		8.139	
		P	0.000*		0.000*		0.000*		0.000*		0.000*	

DP = distal phalanges, MP = middle phalanges, PP = proximal phalanges, MC = metacarpal bone. *$p < 0.05$ is significant.

Table 3
Comparison between the right and the left hand bones in males and females by using student t-test.

Bone Rt & Lf		Fingers									
		1st		2nd		3rd		4th		5th	
		M	*F*	*M*	*F*	*M*	*F*	*M*	*F*	*M*	*F*
DP	*t*	1.949	0.350	1.307	0.440	0.000	0.496	0.984	1.030	0.000	0.270
	P	0.057	0.728	0.197	0.662	1.000	0.622	0.330	0.308	1.000	0.789
MP	*t*	None	None	0.221	0.111	0.141	0.270	0.163	1.124	0.531	0.655
	P	None	None	0.826	0.912	0.888	0.789	0.871	0.267	0.598	0.516
PP	*t*	0.275	0.000	1.492	0.714	1.695	1.243	2.030	0.798	0.286	1.091
	P	0.785	1.000	0.142	0.478	0.096	0.220	0.048	0.429	0.776	0.281
MC	*t*	3.584	0.230	1.750	0.207	0.765	0.538	1.244	1.014	1.500	0.889
	P	0.001*	0.819	0.086	0.837	0.448	0.593	0.219	0.315	0.140	0.378

M = male; F = female; Rt = right; Lf = left; DP = distal phalanges; MP = middle phalanges; PP = proximal phalanges; MC = metacarpal. $p < 0.05$ is significant*.

Table 4
Multivariate logistic regression analysis with the use of most predictable measurements of both hand bones to determine sex.

	Variables	*B*	SE	Wald	Df	Significance	Exp (*B*)
Step 1	Lf PP1	−1.107	0.2270	23.874	1	0.0000	0.3310
	Constant	34.216	6.991	23.955	1	0.0000	7.240
Step 2	Lf PP1	−0.751	0.2420	9.604	1	0.0020	0.4720
	Lf MC4	−0.308	0.1210	6.509	1	0.0110	0.7350
	Constant	40.926	7.958	26.450	1	0.0000	5.939
Step 3	Lf PP1	−1.454	0.420	11.965	1	0.001	0.234
	Lf MC4	−0.536	0.171	9.824	1	0.002	0.585
	Rt PP2	0.859	0.319	7.240	1	0.007	2.360
	Constant	41.821	9.637	18.833	1	0.0000	1.455
Step 4	Lf PP1	−1.644	0.4900	11.241	1	0.0010	0.1930
	Lf MC4	−0.496	0.1890	6.869	1	0.0090	0.6090
	Rt PP2	1.596	0.5190	9.461	1	0.0020	4.931
	Rt PP3	−0.855	0.390	4.805	1	0.0280	0.4250
	Constant	54.452	13.954	15.227	1	0.0000	4.449
Step 5	Lf PP1	−1.746	0.5140	11.534	1	0.0010	0.1740
	Lf MC4	−0.640	0.2310	7.690	1	0.0060	0.5270
	Rt PP2	1.559	0.5190	9.028	1	0.0030	4.752
	Rt PP3	−1.310	0.4760	7.577	1	0.0060	0.2700
	Rt PP4	0.815	0.425	3.669	1	0.0550	2.259
	Constant	53.584	13.645	15.422	1	0.0000	1.868

Rt = right; Lf = left; PP = proximal phalanges; MC = metacarpal; 1 = first finger; 2 = second finger; 3 = third finger; 4 = fourth finger; SE = standard error; Wald: χ^2; df = degree of freedom; p = significance; Exp = exponential.

4. Discussion

Many studies have been attempting to determine sex by using different body features such as foot shape, foot print ratio, foot and shoe dimensions, the femoral head, the patella, long bones of the arm and the teeth. Very few studies were done for the determination of sex from foot and hand dimensions.[2,14,18,19]

The aim of this study is to assess the accuracy of sex determination from the length of all metacarpals and phalanges of right and left hands using X-Ray radiographs and to develop a discriminant formula that can be used in the Egyptians.

The present study focused on one measurement (length) because the other measurements (the width of the base and head) of metacarpals and phalanges are not accurate on routine hand radiographs.[12]

The present study revealed that the majority of measurements were slightly longer in the right hand than the left hands in females, while in males the majority of measurements were slightly longer in the left hand than the right hand; but with no significant difference in the measurements between right and left hands in either sex except for the first metacarpal bone in males that could be explained by daily activities which could affect the growth of bones.

Table 5
The correct classification of sex by using the multivariate logistic regression of both hands.

Sex	Original	Predicted group		Accuracy %	
		Male	Female	Correct	Incorrect
Males	50	47	3	94 %	6 %
Females	50	6	44	88 %	12 %

Overall predictive value is 91 %.

The present results were in agreement with those reported by Krishan et al.[20,21] who studied the limb asymmetry and stated that total upper extremity length, upper arm length and forearm length were longer on the right side while hand length, total lower extremity length and lower leg length were longer on the left side. All the limb dimensions except for hand length showed statistically significant asymmetry ($p < 0.01$).

Furthermore, the finding of metacarpal length was in contradiction with that of Manolis et al.[13] in Athens population, who stated that the right metacarpals were generally longer than those of the left hand in both sexes with exceptions in some measurements but these differences were not statistically significant. Also the present results were on contrary to that of McFadden and Bracht[22] in European and African American populations, who stated that the right hand was slightly longer than the corresponding bones in the left hand, but the differences were small and there were numerous exceptions. Also Krishan et al.[2] found that hand and foot dimensions were significantly higher ($p < 0.001$) in men in both right and left sides. Hand length was found to be

Table 6
Multivariate logistic regression analysis with the use of most predictable measurements of the right hand and left hand bones separately to determine sex.

	Variables of Rt hand	*B*	SE	Wald	Df	Significance	Exp (*B*)
Step 1	MC4	−0.554	0.1050	28.073	1	0.0000	0.5750
	Constant	31.914	6.032	27.990	1	0.0000	7.247
Step 2	PP1	−0.574	0.213	7.295	1	0.007	0.563
	MC4	−0.338	0.125	7.341	1	0.007	0.713
	Constant	37.233	7.335	25.769	1	0.000	1.479
Step 3	PP1	−0.890	0.277	10.333	1	0.001	0.411
	PP2	0.458	0.221	4.282	1	0.039	1.581
	MC4	−0.437	0.146	9.031	1	0.003	0.646
	Constant	34.499	7.553	20.862	1	0.000	9.612
Step 4	DP1	−0.627−	0.280	5.008	1	0.025	0.534
	PP1	−0.933−	0.311	8.986	1	0.003	0.394
	PP2	0.648	0.264	6.020	1	0.014	1.911
	MC4	−0.324−	0.150	4.670	1	0.031	0.723
	Constant	35.330	8.078	19.129	1	0.000	2.206E15
Step 5	DP1	−0.634	0.311	4.143	1	0.042	0.531
	PP1	−1.047	0.337	9.668	1	0.002	0.351
	PP2	1.351	0.469	8.281	1	0.004	3.860
	PP3	−0.814	0.385	4.468	1	0.035	0.443
	MC4	−0.258	0.163	2.500	1	0.114	0.773
	Constant	43.602	10.392	17.603	1	0.000	8.634
	Variables of Lt hand	*B*	SE	Wald	Df	Significance	Exp (*B*)
Step 1	MC4	−0.561	0.105	28.798	1	0.000	0.571
	Constant	32.297	6.008	28.894	1	0.000	1.062
Step 2	PP1	−0.749	0.243	9.500	1	0.002	0.473
	MC4	−0.315	0.121	6.767	1	0.009	0.730
	Constant	41.238	8.011	26.500	1	0.000	8.115
Step 3	PP1	−1.189	0.342	12.076	1	0.001	0.305
	PP2	0.680	0.302	5.090	1	0.024	1.975
	MC4	−0.511	0.167	9.412	1	0.002	0.600
	Constant	39.032	8.493	21.123	1	0.000	8.941

Rt = right hand; Lf = left hand; PP = proximal phalanges; DP = distal phalanges; MC = metacarpal; 1 = first finger; 2 = second finger; 3 = third finger; 4 = fourth finger; SE = standard error; Wald: χ^2; df = degree of freedom; *p* = significance; Exp = exponential.

significantly larger on the right side in men only ($t = 2.455$, $p = 0.01$).

Moreover the present results proved that either the right or left hands could be used for sex determination. This is in disagreement with the findings of Smith[9] and Case and Ross[12] who stated that the accuracy rates for the left hand was higher than the right hand. While the studies of Alicioglu et al.[16] in Turkish population and Eshak et al.[4] in Egyptian population; reside on the left hand only because of the fact that the majority of populations are right handed and therefore will be less influenced by activity.

Moreover the present study revealed that males presented with significantly greater mean values than females ($p < 0.05$) for the length of metacarpals and phalanges of all fingers of both hands. The ordering of *metacarpals* (MC) by the length from longest to shortest was $2 > 3 > 4 > 5 > 1$; the ordering for *proximal phalanges* (PP) by the length was $3 > 4 > 2 > 5 > 1$; the ordering of *middle phalanges* (MP) by the length was $3 > 4 > 2 > 5$ and lastly the ordering of *distal phalanges (DP)* by the length was $1 > 4 > 3 > 2 > 5$. This could be explained by mechanical response of the bone owing to the greater muscular demand of males.

Table 7
The correct classification of sex by using the multivariate logistic regression of the right hand and the left hand separately.

Sex	Original	Predicted group		Accuracy % of right hand	
		Male	Female	Correct	Incorrect
Males	50	44	6	88 %	12 %
Females	50	6	44	88 %	12 %
Sex	Original	Predicted group		Accuracy % of left hand	
Males	50	45	5	90 %	10 %
Females	50	6	44	88 %	12 %

Overall predictive value is 88 % for the right hand and 89 % for the left hand.

As regard the metacarpal bones, the present study was in agreement with the studies of Manolis et al.[13] in Athens and McFadden and Bracht[22] in USA which stated that male metacarpals were longer than those of females. Also McFadden and Bracht[22] mentioned that the ordering of metacarpals by the length from longest to shortest was $2 > 3 > 4 > 5 > 1$.

Regarding the ordering of proximal phalanges the present results were in agreement with Garrido and Thompson[23] who stated that the length order (from longer to shorter) of proximal phalanges was found to be $3 > 4 > 2 > 5 > 1$.

These findings were on contrary to Alicioglu et al.[16] study on Turkish, who mentioned that male measurements were greater than females except for distal phalanges. Furthermore Eshak et al.[4] study on Egyptians by using computed tomography; stated that males presented with significantly greater mean values than females for the length of the distal phalanges of all fingers, 1st and 3rd proximal phalanges and all metacarpals. Neither the middle nor the 2nd, 4th or 5th proximal phalanges showed significant differences between males and females.

Comparing between different populations, the present study stated that the length of *all metacarpals and phalanges* of the left hands for both Egyptian males and females were greater than the measurements taken by Alicioglu et al.[16]; on a sample of Turkish population.

Also the length of *all metacarpals* of both the right and left hands of both Egyptian sexes were greater than the measurements taken by Manolis et al.[13]; McFadden and Bracht[22] on a sample of Athens and European American populations respectively.

While the measurements of *all metacarpals* of both right and left hands of both Egyptian sexes in this study were smaller than the measurements taken by McFadden and Bracht[22] on a sample of African American population.

Table 8
Cutoff values (in mm) and accuracy percentage for sex determination for each bone ($n = 100$).

Bone	Cutoff values	Accuracy %	Total %
Rt 1st DP	Male < 21.50 < Female	Female: 85.7% Male: 80%	82.8 %
Rt 2nd DP	Male < 17.50 < Female	Female: 63.3% Male: 82%	72.6 %
Rt 3rd DP	Male < 17.50 < Female	Female: 81.6% Male: 70%	75.8 %
Rt 4th DP	Male < 18.50 < Female	Female: 77.6% Male: 74%	75.8 %
Rt 5th DP	Male < 16.50 < Female	Female: 85.7% Male: 76%	80.8 %
Rt 2nd MP	Male < 22.50 < Female	Female: 79.6% Male: 54%	66.8 %
Rt 3rd MP	Male < 28.50 < Female	Female: 71.4% Male: 76%	73.7 %
Rt 4th MP	Male < 27.50 < Female	Female: 69.4% Male: 70%	69.7 %
Rt 5th MP	Male < 18.50 < Female	Female: 91.8% Male: 58%	74.9 %
Rt 1st PP	Male < 30.50 < Female	Female: 87.8% Male: 80%	83.9 %
Rt 2nd PP	Male < 41.50 < Female	Female: 59.2% Male: 86%	72.6 %
Rt 3rd PP	Male < 44.50 < Female	Female: 81.6% Male: 74%	77.8 %
Rt 4th PP	Male < 41.50 < Female	Female: 77.6% Male: 62%	69.8 %
Rt 5th PP	Male < 32.50 < Female	Female: 81.6% Male: 64%	72.8 %
Rt 1st MC	Male < 46.50 < Female	Female: 71.4% Male: 72%	71.7 %
Rt 2nd MC	Male < 68.50 < Female	Female: 77.6% Male: 76%	76.8 %
Rt 3rd MC	Male < 65.50 < Female	Female: 77. 6% Male: 86%	81.8 %
Rt 4th MC	Male < 57.50 < Female	Female: 83.7% Male: 80%	81.8 %
Rt 5th MC	Male < 52.50 < Female	Female: 89.8% Male: 72%	80.9 %
Lf 1st DP	Male < 21.50 < Female	Female: 80% Male: 84%	82 %
Lf 2nd DP	Male < 21.50 < Female	Female: 84% Male: 66%	75 %
Lf 3rd DP	Male < 21.50 < Female	Female: 86% Male: 62%	74 %
Lf 4th DP	Male < 21.50 < Female	Female: 78% Male: 70%	74 %
Lf 5th DP	Male < 21.50 < Female	Female: 80% Male: 76%	78 %
Lf 2nd MP	Male < 21.50 < Female	Female: 66% Male: 76%	71 %
Lf 3rd MP	Male < 21.50 < Female	Female: 72% Male: 74%	73 %
Lf 4th MP	Male < 21.50 < Female	Female: 70% Male: 74%	72 %
Lf 5th MP	Male < 21.50 < Female	Female: 72% Male: 74%	73 %
Lf 1st PP	Male < 21.50 < Female	Female: 88% Male: 82%	85 %
Lf 2nd PP	Male < 21.50 < Female	Female: 78% Male: 68%	73 %
Lf 3rd PP	Male < 21.50 < Female	Female: 84% Male: 70%	77 %
Lf 4th PP	Male < 21.50 < Female	Female: 74% Male: 82%	78 %
Lf 5th PP	Male < 21.50 < Female	Female: 68% Male: 76%	72 %
Lf 1st MC	Male < 21.50 < Female	Female: 76% Male: 76%	76 %
Lf 2nd MC	Male < 21.50 < Female	Female: 82% Male: 82%	82 %
Lf 3rd MC	Male < 21.50 < Female	Female: 82% Male: 88%	85 %
Lf 4th MC	Male < 21.50 < Female	Female: 82% Male: 86%	84 %
Lf 5th MC	Male < 21.50 < Female	Female: 88% Male: 70%	79 %

Rt = right; DP = distal phalanges; MP = middle phalanges; PP = proximal phalanges; MC = metacarpal; 1st = first finger; 2nd = second finger; 3rd = third finger; 4th = fourth finger; 5th = fifth finger.
Lf = left; DP = distal phalanges; MP = middle phalanges; PP = proximal phalanges; MC = metacarpal; 1st = first finger; 2nd = second finger; 3rd = third finger; 4th = fourth finger; 5th = fifth finger.

These differences could be the result of genetic factors or environmental ones affecting growth and development (nutrition, physical activity, pathological conditions).

A study done on Egyptian population by Eshak et al.[4] by using CT scan; revealed that the measurements of all metacarpals and phalanges of the left hand of both sexes were slightly smaller than the measurements of the present study. This small difference could be explained by the different methods used for the measurements and the difference in their accuracy and may be due to the different sample size.

Furthermore Habib and Kamal[24] studied the length of phalanges of the right and left hands in both Egyptian sexes with the exclusion of thumb fingers because of their flexibility as compared to other fingers which are straight. The measurements of the distal phalanges of both right and left hands in both sexes were greater than those of the present study; while the middle and proximal phalanges of both right and left hands of both sexes were smaller than those of the present study. This could be explained by different size sample and the difference in the method of measurements as they measured the phalanges as the distance between two phalange ridges by help of sliding caliper from the palmer side.

In addition to the previous findings, the present study indicated that five bones of both hands (left 1st proximal phalanges, left 4th metacarpal and right 2nd; 3rd and 4th proximal phalanges) were useful bones for sexing of Egyptian population and showed sexual dimorphism with accuracy 91% *(94 % for males and 88 % for females)*. This is explained by differences in body size between both sexes. The regression equation should be applied cautiously for different population and time periods. Besides, the gathering of all the 19 bones is not easy and measurements consequently calculating process is time consuming and exhausting task.

While by using the right hand only; five bones also (1st proximal and distal phalanges & 2nd; 3rd proximal phalanges & 4th metacarpal) were useful bones for sexing of Egyptian population and showed sexual dimorphism with accuracy 88%. On the other side, by using the left hand only; 3 bones (1st & 2nd proximal phalanges & 4th metacarpal) were useful bones for sexing of Egyptian population and showed sexual dimorphism with accuracy 89% *(90 % for males & 88 % for females)*.

This is in contrast to Alicioglu et al.[16] who obtained 72.7% accuracy for males (16/22) and 90.7% for females (39/43) by using the left hand only.

The misclassification in sex determination could be explained by wrong classified cases (i.e. males of reduced dimensions or females with very strong musculature) and due to individual and genetic variances.

Regarding the accuracy of each bone, the present results revealed that 1st DP & PP and 3rd and 4th MC are the best bones that can be used in correct sex determination.

This is in accordance to Manolis et al.[13] in Athens population who proved that 3rd & 4th MC had the highest percentage of correct prediction. In addition Stojanowski[25] in New Mexico revealed that the 4th MC had the highest accurate estimate.

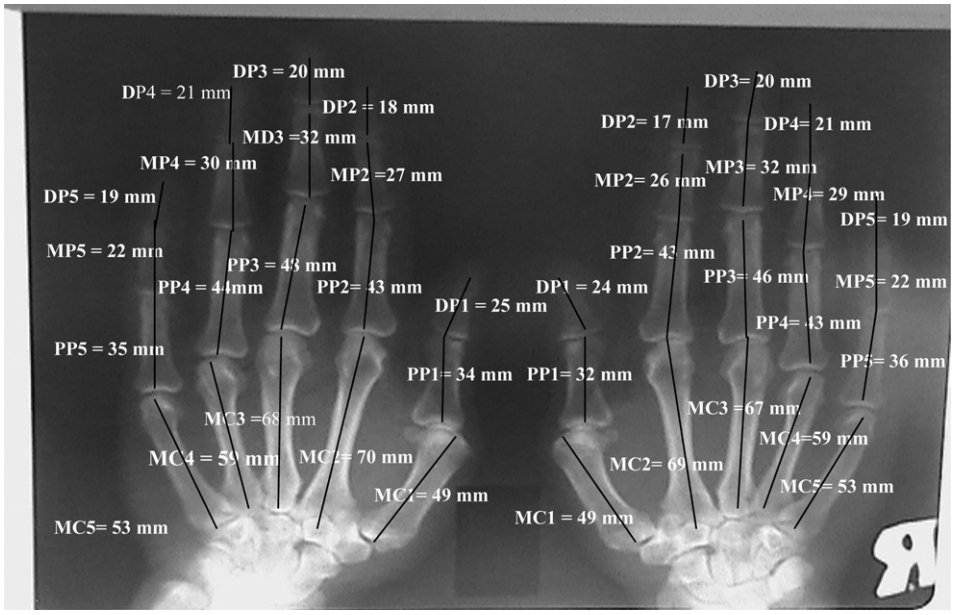

Fig. 1. A radiograph demonstrates the measurements of all metacarpals and phalanges of the right and the left hands (MC = metacarpal; PP = proximal phalanges; MP = middle phalanges and DP = distal phalanges).

On the other hand, Eshak et al.[4] in Egyptian population proved that the 2nd & 5th MC and 1st and 3rd PP had the highest accuracy. Furthermore, Falsetti[26] in European and African American stated that 2nd, 4th and 5th MC could provide method for sex assessment. Moreover Shreuer and Elkington[27] in British White population found that 1st MC had the highest degree of accuracy in identifying sex. In consistent with the present result Barrio et al.[15] in Spanish population found that the 2nd, 4th and 5th MC had the highest accuracy.

These differences could be explained by different populations, different sample size and different methods used in the study.

5. Conclusion

Results of the current study suggest that the length of metacarpals and phalanges of both hands *(especially the 1*st *DP & PP and 3*rd *and 4*th *MC)* could be used for sex determination with reasonable accuracy. Also the X-ray radiographs are good non invasive and simple tool in the determination of sex from the hand bones. Furthermore the regression equation for both hands and each hand separately is specific to Egyptian population and should be used validated before use in other populations.

Conflict of interest

The authors declare that there are no conflicts of interest with any institution or organization.

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Ethical approval

This work was approved by the Institutional Research Ethics Committee of Faculty of Medicine, Mansoura University.

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